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PRINCIPLES OF FEDERAL HYDRO-ELECTRIC POWER DEVELOPMENT

by William Whipple, Jr., M. ASCE

POWER DIVISION

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PRINCIPLES OF FEDERAL HYDRO-ELECTRIC POWER DEVELOPMENT

William Whipple, Jr.,[1] M. ASCE

INTRODUCTION

The activities of the Federal Government in the field of electric power during the last twenty years have been conducted in an atmosphere of intense controversy. There are few facets of American life where there is so much need for clear and objective thinking. Unlike many politically controversial fields where most of the elements are intangibles, the production of electric power can be analyzed quite precisely in quantitative terms; and it appears that by objective application of engineering and economic principles, the area of agreement could be extended much further, and the nature of the political questions thereby more accurately defined. This paper discusses principles of Federal hydro-electric power development and its economic utilization in conjunction with privately owned thermal electric systems.

Hydro-electric power development, as a part of national water resource development, must be related to increasingly complex multiple-purpose river basin plans, and to policies governing the utilization of the nation's water resources. However, it also forms an element of the national electric power industry, since Federal power is fast being integrated with other major sources of power into a galaxy of operationally and economically inter-related systems. Therefore, any broad approach to hydro-electric power development must encompass the respective standards and criteria of water resource development and of electric power generation and distribution.

In meeting the requirements of these two overlapping program fields, Federal hydro-electric power development should be based upon sound engineering, but equally upon sound economic principles; and its values should be equally authentic from the business and the government points of view.

The Federal Hydro-Electric Power Programs

Origins

The original entry of the Federal Government into the field of generation of hydro-electric power was very slow and indirect. After a considerable period of regulation by various officials, the Federal Water Power Act of 1920 created the Federal Power Commission and inaugurated the general system of regulation of private and municipal power which with modifications is still in effect today. Until the late 1920's it was generally accepted public policy that hydro-electric power was to be developed by private capital or locally by municipalities, with Federal regulation in the public interest, mainly to curb harmful monopolistic effects.

Meanwhile the direct activities of the Federal Government in water

1. Colonel, Corps of Engrs., Washington, D. C.

resource development were almost entirely confined to navigation improvements of harbors and inland waterways by the Corps of Engineers, and irrigation of the arid lands of the west by the Bureau of Reclamation. Statutory authorities of these agencies allowing development of hydro-electric power incidental to their respective programs were conservatively interpreted for a long time and actual Federal installations were minuscule.

The first sizable Federal hydro-electric installation was the Wilson Dam at Muscle Shoals on the Tennessee River, which was authorized for national defense purposes in 1916, with an accompanying steam plant, but was not finished until 1925. The long-continued controversy over the construction and the sale of power from this project, which included both steam and hydropower, characterizes it as a historical anachronism, rather than as the forerunner of Federal power programs.

More in line with basic trends, and of interest today as early examples of a Federal-private "partnership" concept, were a number of cases in which private companies were allowed to build powerhouses integral with locks and dams constructed by the Corps of Engineers in the interests of navigation, with some reimbursement for the benefit derived.

The modern era of Federal hydro-electric power developed through systematic planning was forecast in 1927 with H. D. 308, 69th Congress, 1st Session. Upon approval of this report by the Congress, the Corps of Engineers was authorized to prepare a series of comprehensive river basin plans, to include not only navigation, flood control and irrigation, but also hydro-electric power and other project purposes. The resulting reports, often referred to as "308" reports, have since been supplemented by later planning of the Corps, and of other Federal and Non-federal agencies. The first major Federal multiple-purpose project adopted as a normal water resource development was the Hoover Dam, authorized by the Boulder Canyon Project Act of 1928, and constructed by the Bureau of Reclamation.

Since that time, a number of individual multiple-purpose projects and large systems of projects have been planned, and are being constructed by the Federal Government. Multiple-purpose systems of reservoirs properly planned and with integrated operations, can often produce hydro-electric power and serve other important purposes such as flood control or irrigation much more economically and effectively than could be done if projects were developed individually, or for hydro-electric power alone. During the same period private power companies and, less frequently, municipal and state agencies have planned and constructed effective hydro-electric power systems.

Generally speaking the Non-federal systems are not of the largest magnitude and are planned in areas where project purposes other than power are not of major importance. The broad distinction between the scope of Federal and of Non-federal programs is fairly well understood; but there is plenty of room for controversy, particularly as to whether specific reservoir sites remaining should be developed by Federal, state, municipal or private agencies.

The Role of Hydro-Electric Power

As of 1944 and 1954 the relative magnitude of the Federal hydro-electric power programs as compared with the total national aggregate electric utility capacity is as shown in Table I. While the nation obtains and will continue to obtain the bulk of its electric energy from privately-owned thermal power, Federal hydro-electric power is a considerable factor. However, there is

danger of exaggerating the importance of hydro-power if estimates of hydraulic energy potentially available are evaluated without full weight given to limitations of economic cost. For example, estimates of available hydro-electric potential of the New England states have been approximately 3,000,000 kilowatts but recent economic evaluations of the New England-New York Inter-agency Committee show that only 947,000 kilowatts could be considered as having feasibility under private financing of as high as 0.80/1.0 (where 1.0/1.0 is the criterion of currently profitable operation). Moreover, in other areas certain projects of unquestioned feasibility and very great economic value cannot be built on account of difficulties involving wildlife, park development or other intangibles. There are only two major areas, namely, the Columbia and Tennessee Valleys, where Federal power is of magnitude anywhere near comparable to private power, and only one, the Columbia, where hydro-electric power is the predominant source of energy. The Tennessee Valley virtually completed development of feasible sites some time ago. Outside of the large undeveloped potential on the Columbia and St. Lawrence systems, remaining economically feasible projects not yet authorized are generally small compared to future power needs of the regions concerned. Unless fuel costs become relatively much higher than they are today, future basin planning is unlikely to develop new feasible power sites anywhere nearly proportionate with the growth in demand for power. Hydro-power is and will remain an auxiliary power source, so far as the national picture is concerned; and even in the Columbia basin the hydro-power cheaper than steam can be fully utilized within about 20 to 25 years, if the current rate of growth continues.

The Federal Hydro-Electric Power Developments

The hydro-electric power programs of the three principal Federal construction agencies in this field are summarized in Table II. It will be noted that the Corps of Engineers now has by far the largest of the construction programs of hydro projects. The installation schedule of the Corps, shown in Figure 1, includes projects currently underway in the Chattahoochee, Cumberland, White, Missouri, Columbia and Willamette Basins. Almost all Corps projects serve important purposes of flood control and navigation as well as power, and some of them are of great size and complexity. For example, Figure 2 shows McNary Dam on the Columbia River, a project which will extend an important navigation channel and generate initially 980,000 kilowatts of power at an estimated cost of $287,000,000.

Power produced from Corps of Engineers projects, with one minor exception, is marketed by four Interior Department agencies, each in its own area, namely, the Bonneville Power Administration, the Bureau of Reclamation, the Southwest Power Administration and the Southeast Power Administration.

Processes of Developing and Administering Federal Hydro-Power

Water resource projects of the Corps of Engineers, whether or not power is involved, must develop through a series of five phases, which are roughly similar to stages in development of a privately financed venture.

1) General planning (preliminary examination, survey and review reports)
2) Authorization (by River and Harbor or Flood Control Act)
3) Preconstruction planning (usually called advance planning)
4) Funding and construction (thru Appropriations Acts)
5) Operating and maintaining

The first stage, general planning, is one of project development. The project may originate as an element of an original comprehensive basin plan, as an isolated project, or as a modification of a previously accepted basin plan. In any event, the location, scope and approximate cost of the best project must be determined by field surveys and office studies, including analyses to determine the economic feasibility. This general planning phase is extremely important, and the principles involved are covered in more detail in a later section. In the Corps of Engineers, the report is prepared under supervision of the appropriate district engineer, and reviewed by the division engineer, the Board of Engineers for Rivers and Harbors, and the Chief of Engineers. The latter then obtains views of the Governors of the States concerned and of other interested Federal agencies, and forwards the report through the Secretary of the Army and the Bureau of the Budget. The Public Works Committees of the House and Senate then consider the report, and after Congressional hearings, at which parties interested are called on to testify, the project may be authorized for construction. In 1954, Congress passed the first authorization bill for Corps of Engineers projects since 1950; it authorized a little over one billion dollars in new projects including flood control, navigation and power, or about half of the volume of such construction during that same four-year period.

Since the middle thirties, inter-agency cooperation has become an increasingly important and complex aspect of comprehensive basin planning. Prior to World War II the most important project authorizations were based upon reports of a single Federal agency, with frequently only nominal consultation with State and other Federal agencies. Studies leading to the two most important basin authorizations since that time, namely, those in the Columbia and Missouri Basins, included a great deal of inter-agency cooperation and integration of planning; but there was not complete merging of the major programs until the planning process was largely complete. At the present time, in addition to normal cooperative procedures between both State and Federal agencies, there are two important truly joint planning undertakings being completed, those for the New England-New York area and for the Arkansas, White, and Red Basins. Joint planning and other new techniques, which allow more time and earlier opportunities for consideration of State interests, and for evaluating a variety of collateral but still important project purposes such as recreation, wildlife conservation and pollution control, may be expected to make Federal planning processes even more complex in the future.

Despite the lengthy process of planning and review outlined above, the project upon authorization is still not assured of early construction. In fact, the authorizations in earlier years so far outstripped construction that recently it has been found desirable to make a review of the entire authorized project backlog. During the winter of 1953-4, authorized projects of the Corps of Engineers totalling 4 billion dollars in estimated cost were administratively separated out from the "active" program either as "inactive" or as requiring reevaluation prior to construction. These projects remain legally authorized; but are unlikely to be built unless and until subsequent reexamination shows them to be definitely sound from both engineering and economic points of view.

In order to prepare authorized projects for construction, a stage of preconstruction planning and design must be carried out. For large multiple-purpose projects this process requires two or more years and hundreds of thousands of dollars. In this stage, after comparative analysis of various alternatives, the exact site and height of the dam are determined, a plan is

made for use of storage for each project purpose, and a general plan of operation is worked out for optimum performance, in conjunction with other projects of the system. Detailed hydro-meteorological studies are made to determine spillway capacity and flood control aspects so that construction can be initiated on a large scale without delay. Based on these designs, cost estimates are refined with more accuracy. The project is now ready to be considered by the Bureau of the Budget and by the Congress for selection as a "new start," for which initial construction funds will be appropriated.

Water Resource Planning For Hydro-Electric Power

General

In principle, all water resource planning should be "comprehensive" in that proposed developments are to be considered from the broadest practicable point of view. Potential direct economic advantages for primary purposes such as development of electric power and flood control must be weighed one against the other and against collateral purposes and intangibles such as preservation of natural scenic beauty. The interests of the present must be balanced against those of the future, and the evaluation of each apparent advantage or disadvantage should be truly objective and, insofar as practicable, quantitative. However, there is no magic in the word comprehensive, and no available rule as to how various criteria should be weighed.

In practice, it would result in overwhelming complexity to go through the endless ramifications of the comprehensive planning process for each phase of planning. A simple, practical approach must be found to solve problems involving only a restricted locality, or a single specialized field. Sub-basin problems which can be solved adequately separate from the main basin plan should be so separated. Moreover, the ideal of comprehensive basin planning of water resources must not overlook the fact that certain water resources are at least as closely related to other economic activities as they are to each other. Harbor improvement is related to port development, watershed improvement is related to agriculture, and hydro-electric power production is related to thermal power production, each more closely than the three are related to one another. Individual projects may have an astonishing variety of economic aspects and relationships. In using the word comprehensive we should mean planning that is sound from the broadest possible point of view; but the basic joint participation of all agencies and interests concerned in a comprehensive basin plan must be supplemented by much simpler working arrangements whereby specific problems can be handled by those agencies best qualified to solve them.

Economic Objective

Federal projects are commonly evaluated as to their economic feasibility in terms of a benefit-cost ratio. This concept, which is essential to an understanding of Federal water resource development, has been explained in the so-called "Green Book" prepared in 1950 by a subcommittee of the Federal Interagency Basin Committee.[2] Whereas an analysis made by a private power company considers the financial costs and returns to the company itself, the Federal Government considers costs and benefits, evaluated in economic terms, to whomsoever they may accrue.

2. "Proposed Practices for Economic Analysis of River Basin Projects," Federal Interagency Subcommittee on Costs and Benefits, May 1950.

It might be thought that sound Government planning would provide the same physical system as would be provided by sound private planning, if the public interest were preserved by normal licensing and other control procedures. However, entirely aside from the quality and disinterestedness of planning, there are general economic reasons why Government planning takes a longer range view. Government operations have an inherent advantage as regards interest rates, whether the problem is one of constructing and maintaining a public building or a hydro-electric development. As applied to hydro-electric projects, with their great capital investments and long periods of construction, this advantage becomes of considerable importance. The Government in effect looks further ahead, and values benefits to the future more highly relative to immediate returns, than any private company can afford to, by reason of the lower interest rate applicable to Federal investment.

In analyzing potential water resource development for a given area, the plan showing the highest benefit-cost ratio is not necessarily the best plan, even disregarding intangibles entirely. Neither is the plan which shows the largest water resource development for which the benefits exceed the costs. The correct economic objective is the maximizing of net benefits, whether we are considering the number of projects and project purposes in a comprehensive basin plan or merely the addition of another generator to a power house. This conclusion results from a basic incremental analysis; if the increment under consideration does not produce benefits greater than its costs, its inclusion in the plan is not warranted. (To economists this is the principle of marginal utility.) The parallel with the approach of the adequately financed entrepreneur, who aims to maximize total profit (rather than profit ratio), is apparent. The benefit-cost ratio is of major importance, along with other factors, in determining the relative merits of plans and projects in the national program, but is properly used incrementally with the objective of maximizing total net benefit.

Value of Power

Sound economic principles require that value of commodities be determined in general by sale price. However, curious and totally unacceptable results are obtained if it is postulated that the output of Federal hydro-electric plants be valued at the current sale price for such power. For example, in 1948, in the Pacific Northwest, firm power from Bonneville and Grand Coulee dams was being sold wholesale at load center at about 2-1/2 mills per kilowatt hour. If this figure were accepted as a measure of value, as was at that time tentatively proposed, few, if any, of the new hydro projects then being considered could be shown to be economically feasible, since they would produce firm power at site at from about 1.6 to 3.0 mills, which after distribution charges of about one mill were added would leave them unjustified. Yet private power companies, then and since, were building smaller hydro projects within or above this price range, in preference to steam plants, which would be more expensive.

The reason for this apparent paradox was, of course, that Federal power is not sold at the highest price obtainable under competitive conditions, but at a rate computed so as to return the original investment. The Bonneville and Grand Coulee dams were built prior to World War II, at the low prices then prevailing, and the low rates charged were ample to amortize the investment. However, these rates could not properly be used as a measure of value.

It may well be asked why existing private utility rates are not used as a measure of value. Private utility rates also are not truly competitive but are

set by regulation, and in some cases they may be based on old inefficient plants. Moreover, rates set are generally retail rates, whereas the Government is interested in obtaining value of wholesale sources of power at site.

A third method of determining value in practice might be by actually negotiating a sale price with utilities which might buy the power. However, since hydro-electric plants take so long to build this would have to be done years in advance; moreover, it would leave the determination of the value of the improvement in the hands of those who might prefer that the Government not undertake such an enterprise.

The method of determining power values employed by the Federal power Commission, and used for estimates for the Corps of Engineers, is based upon the constantly expanding market for electric power produced by thermal plants, and the fact that in the period during which any hydro plant is being designed and constructed, a steam plant can be built to meet the same need. In most parts of the country the value of needed electric power must be as much as the cost of producing equivalent power from steam plants of modern design through private financing, since if the hydro plant is not adopted the thermal alternative will actually be built. On the other hand, since private steam plants can and will be built to meet practically any power demand, provided rates are sufficiently high, the value of power produced by a hydro plant cannot be said to exceed the cost of producing equivalent power by steam. The analysis is made on the basis of at site costs in both cases, with due allowance for difference in transmission costs to load centers.

The only major exception to the use of above method is in the Pacific Northwest, where estimated cost of thermal power plants is so much greater than costs of hydro power potentially available that a considerable part of the estimated demand would not utilize thermal power at its higher costs. Therefore, for evaluation of power to meet the higher load estimates, values below the costs of thermal power are especially estimated.

There are special problems of valuation connected with intermittently available energy and with peaking power, which are covered in the section beginning on page 9.

Taxes Foregone By Public Development

It has long been a source of resentment on the part of private power companies that the substantial taxes which they pay are used by Government, along with other revenues, to build tax free Government hydro-electric power projects whose costs are then often referred to as a "yardstick." Since the taxes on a private utility may constitute 20% or more of its gross revenue, this is a major issue. It is considered that Government power projects should not be built (other than for research, etc.) unless their costs compare favorably with private costs after allowance for the "taxes foregone." Taxes foregone are defined as taxes which will be paid by the private utility if it generates the power but will not be paid if the Government project is built instead. If this criterion is not followed, Government hydro plants may be built which will actually utilize more materials and labor in proportion to power produced than the private steam plants which they will replace.

The other overhead cost difference involved, that of interest rates paid, appears to be primarily a matter of financial return. Insofar as interest is the price of capital, a higher rate affects the amount of money paid for use of capital but not the amount of capital used. Unless it can be shown that the advantage of low Federal interest rates has compensating economic

disadvantages of a "real" nature, the economic costs of Federal projects should continue to be computed at the lower rate. This issue is one of basic economic principle, which is sufficiently important to warrant more intensive analysis than it appears to have been given.

In meeting the issue of taxation, the Corps of Engineers for the Department of the Army, the Interior Department, and the Federal Power Commission agreed in March 1954 that thereafter taxes foregone by Federal development of water power should be considered as an economic cost to be added to other project costs for purposes of comparison with benefits in order to determine benefit-cost ratios and economic feasibility. This change in approach required a recomputation (and material reduction) during 1954 of benefit-cost ratios for all Corps of Engineers projects in the United States; and the testimony to Congress on appropriations during the spring of 1954 was based upon the new criteria.

Combination of Power with other Functions

Since the objective of modern basin planning is to obtain optimum results from the point of view of all project purposes, the combination of functions in a given reservoir must be carefully planned. However, this point can be and often has been overemphasized, the public impression sometimes being created that a second rate project can automatically be made a very good one merely by the inclusion of a larger number of project purposes (to which a large part of the costs can be charged). Such valid but usually intangible benefits as recreation, fish and wildlife, pollution control, and sediment retardation may be exaggerated by proponents of a project. Also there have been cases where flood control benefits have been claimed without the corresponding reservation of reliably available flood control storage. All of these purposes and others can, of course, be added advantages to the extent that appropriate circumstances exist, but the results must be determined by careful quantitative analysis and are highly specific to the circumstances of the particular project and locality.

The combination of major project purposes most uniformly favorable is that of navigation and power. With the aid of modern lock designs a series of navigation dams on a large river can often be constructed with head differentials large enough to allow the economic generation of power at each site, as on the Tennessee, Cumberland and Columbia Rivers. Since in such cases only minor draw down storage is desirable for pondage in the interests of power, operation for the two purposes can be combined with very little added cost or loss to either purpose. There is a certain use of water for lockage, and power pondage requires locks to be a few feet greater in height. Peaking operation of power plants can, of course, cause sudden flow variations detrimental to navigation and undesirable for other reasons; but adverse effects can be minimized by adequate pool overlap, except for the lowest dam of a series. Annual cycles of storage in the interests of power are usually directly advantageous both to navigation and to other important objectives favored by sustained moderate stream flows.

The combination of flood control and hydro power in a single project requires storage sufficient for the two purposes. In most watersheds of the United States flood flows occur mainly through rainfall and may occur on short notice at various times of the year. In such cases floods are essentially unpredictable until the precipitation occurs; and storage used for power purposes, which is kept filled whenever practicable, may provide only an intermittent, indeterminate degree of flood control.

For areas of major importance, where floods can cause loss of life and serious disruption of regional or national economic life, any partial protection plan has the defect of contributing to an illusory public impression of being satisfactorily protected. The most undesirable aspect of partial protection afforded incidentally to power storage is that rather than contributing uniformly to reduce the damage from all floods it may be fully effective at the time of one major flood but fail to have any effect at all upon the next. Since the intermittently favorable effects of incidental flood storage are at least partially counterbalanced by unfavorable effects of indeterminate magnitude, due to public psychology, it has been Federal policy to evaluate only reliably available flood control storage.

In certain cases, however, floods are partially or wholly predictable. In extensive areas of the west, major floods on large streams always occur from snow melt, so that quite accurate forecasting may be practicable. In such cases combined purpose storage may be wholly or partly filled for power purposes each year, and evacuated as required for such purposes without loss of effectiveness for flood control; provided it is drawn down by the time the water content of snow cover and other conditions have built up a flood potential.

The essential for combining of project purposes into a multiple-purpose project is that each purpose be included only to the extent shown incrementally justified by economic studies, and that the capability of the project to satisfy all project purposes be determined from careful operation studies, covering a wide range of potential meteorological conditions.

Relationship of Thermal Power To Hydro-Power Storage and Installed Capacity

Storage and Head Developments

While there is a wide range of types of hydro-electric projects, there is a basic grouping into storage and head plants, the latter usually incorporating "pondage" for normal daily and week-end operation.

Re-regulating dams and certain other projects such as Bonneville and Gavins Point Dams discharge into reaches where it is essential that variation in discharges be kept within fairly close limits. However, wider variations in discharge are generally allowable, and for Federal plants now planned pondage is usually sufficient to sustain any degree of peaking which is expected to become economically feasible. On account of the importance of flow variations of longer period an analysis of storage potentialities of the stream is a prerequisite to the determination of project characteristics. However, it is essential also to know how the projects in question can be related to adjacent power systems and power markets.

Production of Firm Power

Federal hydro-electric developments in the past were often evaluated largely on the basis of their ability to produce the maximum amount of firm power, of load factor appropriate to supply a group of customers. Other electric energy produced was referred to as secondary or dump and usually considered of little importance. In most parts of the United States, Federal hydro projects are now closely associated with large predominantly thermal power systems. Under such circumstances different concepts become appropriate; and the term firm power becomes ambiguous, except as applied to the marketing area as a whole. The term primary energy will be used to

designate the maximum output of energy which the hydro project in question could produce continuously even throughout the most adverse periods of runoff.

To determine quantitatively the relationships between continuous power and storage we can plot long period hydrographs and power duration curves of the assumed hydrologic cycle of the future. This is usually done by assuming a repetition of the hydrologic cycle of the past with suitable corrections for depletions due to consumptive use of water and effects of reservoirs already built. It should be remarked in passing that the prediction or assumption of the hydrologic cycle of the future based upon records of the past is a process highly empirical and fraught with major uncertainties, and is not always a reliable guide.

The first increments of storage will yield relatively large additions to continuous power, whereas the storage required to bring the final possible addition to continuous power would have to be spread over many years. These results show a law of diminishing returns applied to incremental storage additions. As an example of this relationship, when a series of storage reservoirs was being considered in 1948 for addition to the power system of the Columbia Basin it was found that the Albeni Falls reservoir would have its benefit-cost ratio doubled if it was considered first rather than last in the group of storage reservoirs proposed. Such variation indicates the importance of assumed order of construction in determinations of feasibility.

Hydro Plants for Peaking

From an engineering point of view, a thermal-hydro system, including hydro projects interconnected and operationally integrated with thermal plants, is much more typical than an all-hydro system. From the point of view of an expanding thermal-hydro system, new hydro projects have first costs per unit of capacity higher than those of new thermal plants; however, if planned for initially, incremental additions to power house to bring a reservoir project to higher peaking capability are normally less expensive than the first cost of additions to steam plant. Therefore, unless a system has a large amount of existing installed capacity in obsolete thermal plants whose operating costs are so high that they can only be used for peaking, the hydro plants will be a more economical source of peaking power than steam. This is especially applicable as regards new additions to rapidly growing systems. Usually installed capacity over 50% greater than average system load is necessary. From a technical point of view most hydro plants are more suitable to meet peak loads and sudden demands than are thermal plants. The hydraulic turbine at partial gate opening is almost instantaneously responsive to load changes. Moreover, all other units can quickly be thrown on the line, without the expense and time required to heat up boilers on steam plants. Therefore, the hydro plant in a thermal-hydro system in addition to furnishing of energy usable under the system load curve, usually has the additional function of providing dependable peaking capacity.

From an economic point of view dependable peaking capacity requires the project to assume a definite part of the peak load, providing necessary power over the required period of the peak. This relationship can readily be indicated by means of a percent-percent curve (or "KW-KWH" curve, as outlined in a recent paper based on Pacific Gas and Electric Company experience.[3])

3. Mr. Walter Dreyer "The Thermal Power Plant as the complement of hydroelectric power in regions of abundant hydraulic potential. World Power Conference 1954.

Such an analysis shows how hydro plants can be shifted towards peak load use during dry periods, and towards base load use in wet periods, in order to utilize fully all available energy for the replacement of fuel in thermal plants. By using such curves, as shown in Fig. 3, it is possible to integrate steam and hydro potentialities into an optimum system and in particular to analyze the critical period load conditions subject to which the hydro project or projects must maintain dependable capacity. The primary energy available is the basic controlling factor, provided that incremental installations adequate to attain economic peaking capability with available primary energy have not been precluded by design provisions of initial construction.

Storage—Installed Capacity Relationships

The yields of additional power due to storage, as mentioned previously, are subject to a supplementary analysis. In place of a hydro system designed with considerable storage to produce maximum primary hydro energy, a possible alternative is to develop a system of hydro plants with little storage but relatively high installed capacities, which will operate on the peak of the load curve during low flow periods. By adjusting the position of the hydro to base load during times of high flow, the large capacity is available to generate fuel replacement energy during off-peak periods. This alternative possibility is important not only to the determination of project and system characteristics but also to headwater benefit determinations.

To approach a sound solution of this question for a thermal-hydro system, storage yield curves may first be drawn showing how for planned head installations both primary and total usable energy are increased with each increment of storage added, as shown in Fig. 4. The primary energy curve and the total energy curve A are based on installed capacity as required to obtain firm power, at a given load factor. Curves B and C show additional increases in total energy with additional installed capacities. A project or combination of projects with storage S and installed capacity A as represented by point "X", could obtain more total energy by increasing its installed capacity to C, as shown by point Y. However, the same addition to total energy, as well as a larger addition to primary energy, could be obtained by making a smaller increase in installed capacity to B together with an increase in storage, as indicated by point Z. To determine which of the alternatives is preferable an evaluation should be made of incremental costs and benefits of the two alternatives.

The influence of interconnected thermal plants on the planning of hydro in a combined system is effective in two ways. In the first place, the replacement of fuel by hydro energy gives considerable value to all energy produced from hydro projects, usually 1.2 - 3.0 mills per KWH. Total usable energy can be made available with less storage by providing higher installed capacity, the relative value of storage increments being thereby limited. The second aspect whereby thermal plants affect value of hydro power is the higher peaking capability which can be utilized at the hydro plant. Instead of basing installations on system load factor, say 65-70%, they are apt to be based on 25% or lower. This result greatly increases the value of the power produced with a given amount of primary energy. Experience in various parts of the United States indicates that usually a good deal of peaking can be taken by older and less efficient thermal plants, so that the extremely high installed hydro capacities which may be indicated by long range extrapolations of current system load curves are not assured of realization in practice. However, it is now generally accepted that practical and economic considerations

generally warrant use of hydro projects as peaking projects; and provision should usually be made in powerhouses for additional units over and above those initially required. Load factors down to 10% may prove to be entirely feasible, if suitable marketing provisions are arrived at. Such developments would show an economic value for many government plants considerably beyond what is now estimated.

Valuation of Power

The valuation of Federal hydro plants in a growing system in which thermal plants are predominant should obviously not be on the basis of firm power which could be produced by these hydro plants if operated separately. Unit values of dependable capacity and of usable energy are obtained, based on incremental costs of obtaining such capacity and such energy by adding to the existing system thermal plants of modern design, with appropriate allowance for transmission. Aggregate values of energy produced are usually based on the average usable energy supplied to the system by the hydro plants. As regards value of capacity, simple averages of project capability are not appropriate; as, unlike energy, peaking capability must be reliably available from hydro plants to be of full value. Some individual hydro projects have no reliable dependable capacity, since some of the lower run-of-river plants are completely drowned out during floods. Storage plants, on the other hand, are drawn down mainly during periods of low flow, and can often produce power at overload rates up to 15% above installed capacities at other times. There may be considerable diversity in peaking capacity between hydro plants of a single system and also between hydro and steam. Also maintenance schedules on large steam systems can be adjusted to allow some flexibility. Therefore, dependable capacity evaluated for groups of hydro projects in steam-hydro systems may properly take advantage of diversity of conditions of hydro generation, and make some additional allowance for the capabilities of hydro which are available the greater part of the time. Such dependable capacity is evaluated in kilowatts, but must be understood to correspond to an appropriate load assignment in terms of energy.

Plans of Operation

After studies such as outlined above, a set of operating criteria will be developed for each new storage project which will define:

a) A planned use of storage to produce maximum total returns, and a resulting primary energy which can be relied on.
b) An installed capacity designed to utilize primary energy most advantageously—in most cases this will be the maximum installation which can be supported in an appropriate position on the load curve to provide dependable capacity.

In any hydro plant designed for peaking, the maintenance of primary energy throughout a drouth period is of very great importance. Such a plant may be able to supply a considerable base load without difficulty in normal years; but if the maintenance of base load throughout a drouth period is reasonably assured, the plant in question is presumably under installed. It should go without saying that use of storage should subordinate the generation of additional usable energy to the assured maintenance of dependable capacity.

Cost Allocation

Cost allocations may be used for a number of purposes, some of which are mainly of theoretical and historical interest. However, allocations of cost to water supply storage may directly determine sums which the municipality must pay for such water from such storage; allocations to flood control may after subtraction determine remaining amounts which are charged to irrigation districts; and, most important for our present purposes, allocations to power cost constitute an investment which must be amortized by suitable rates charged to the power users. Without proper cost allocations the most detailed accounting and auditing cannot reveal the true facts regarding the Government's power investment in multiple-purpose projects.

It has not been possible so far to develop a type of cost allocation which will be incontrovertibly rational and free of empiricism in all respects. It may never be possible. On the other hand we should not be satisfied with suggestions that allocations should be made by a number of different methods and then averaged, or that after the computations are completed final allocations of substantially different character should be made as a matter of judgment. Even though a theoretically perfect solution is not available, economic principles can establish a clear-cut line between the relatively narrow range within which solutions may be empirically refined and the range of demonstrably erroneous proposals.

A cost allocation is similar in principle to those familiar details of cost accounting in either business or government where a car, a building or an individual's time is charged, say, part to one operation and part to another; yet so great are the economic stakes involved that many important projects where the facts are readily established have gone for years with cost allocations widely in disagreement.

As a part of the background for allocation, it must be remembered that a project purpose is properly included in a multiple purpose project only when its benefits exceed the incremental costs of including it. Therefore, if there were allocated to any project purpose more cost than justified by the benefits, the conclusion could only be drawn that the inclusion of this purpose was economically unjustified; and such an allocation would be unreasonable unless this were so. Yet despite this obvious relationship, in case of the McNary project cost allocation, serious proposals were made in 1953-4 that costs should be charged to navigation in amounts at least twice the value which could be justified by the benefits. This would have greatly reduced the allocation to power, and power rates required to be charged, and would have shown that power produced by the project had a very high benefit-cost ratio, while inclusion of navigation would be shown unjustified by a wide margin. Since the cost of the entire dam and reservoir except for the lock would have had to be borne by power if navigation had not been included, and since the costs in question were joint costs of the spillway and reservoir and not of the lock, it can be seen that such an allocation could not possibly be supported. In this case the navigation benefits did not greatly exceed the cost of the lock, and there was only a very narrow margin within which any reasonable allocation could have been made.

Two cost allocation methods which have often been advanced under one pretext or another, while not as far afield as the McNary proposals discussed above, are designed to charge the non-reimbursable project purposes with the maximum permissible amount. These methods respectively make an allocation equal to capitalized net benefits (of the non-reimbursable purpose)

or charge only incremental costs (of the reimbursable project purpose). The latter is the more respectable, having been authorized by Congress in certain special cases. However, both methods have the effect of favoring one project purpose over another; and where not otherwise specially authorized by Congress or clearly shown justified by special circumstances, such methods should not be used. The advantages of multiple purpose development should be equitably shared between project purposes; and any proper procedure for general application should treat project purposes on an equal basis.

A method which is simple and appealing from the common sense point of view is the "use of facilities" method. This procedure can only be applied when the costs being allocated are costs of physical features directly comparable on a quantitative basis. For example, an irrigation ditch which carried water to two equally distant areas could have its costs allocated in proportion to the amount of water carried to the respective areas. This method cannot normally be applied to projects involving power because usually the power utilizes head plus storage while the other project purpose uses storage alone. In theory this method could be applied to a run-of-river plant such as McNary, because both navigation and power use the head and neither uses (appreciable) storage. However, the results in this case, with a 50/50 split of joint costs, would come into conflict with other definite limits. This method does not appear adequate for use on power projects.

After much study of various methods, the Corps of Engineers, the Department of the Interior and the Federal Power Commission in March 1954 defined specifically and adopted for common use a cost allocation procedure based on the "separable cost-remaining benefits" method. The designation is not very descriptive of the method; but the method itself is a reasonable one.

It is based upon three main points of which two are demonstrably valid limits and the third although entirely empirical is equitable. In the first place, each project purpose is charged at least the incremental (or "separable") cost of including that purpose in the project. This is computed as the "specific" cost of features used for a single project purpose (such as a powerhouse, or a lock), less additional costs which would otherwise be entailed by other purposes if the purpose in question were not included (such as an added section of dam required if the lock were not built).

In the second place (unless the project as a whole should have a benefit-cost ratio less than unity) no project purpose is charged more than the benefits created by that project purpose or the annual cost of providing equal benefits in some alternative manner, whichever is less. The necessity of such a limit with regard to benefits is discussed above in sufficient detail with reference to the McNary case. As regards the alternative cost as a limit, it is clear that if for example an equivalent water supply for a city can be obtained by wells rather than by storage in a proposed reservoir, it would be unreasonable to attempt to charge to water supply a greater part of the reservoir cost than the cost of the alternative wells.

The "separable" costs each pertaining to its appropriate project cost, leave joint costs allocable among the purposes. To determine how these joint costs are to be allocated, there is computed for each purpose a "remaining benefit" by subtracting the separable cost from the benefit (or from the alternative cost, whichever is the lesser). Joint costs are distributed in

proportion to the respective "remaining benefits."[4]

The final step as described in the preceding paragraph is empirical, but has the advantage of treating all project purposes equally and of remaining within all essential criteria. Although the details of the method are subject to some differences of interpretation, its application promises to give good results.

In applying to cost allocation procedure the item of taxes foregone, as discussed in the section beginning on page 5, the taxes foregone are included as a portion of the costs of power along with financial costs. For purposes of payout, and allocation of project construction and operation and maintenance costs, taxes foregone are later subtracted.

SUMMARY AND CONCLUSIONS

The Federal agencies made two outstanding advances in 1954 in deciding to acknowledge taxes foregone by private development as an economic cost and in adopting a sound and equitable cost allocation policy. The former decision basically improved project formulation and the latter constitutes the indispensable basis for sound cost accounting and financial payout.

Notwithstanding the fact that Federal projects now authorized were planned without consideration of the tax situation, and without full agreement on cost allocation, they are generally sound when reviewed in the light of the new criteria. This is due to the natural desire to start the best projects first, an unwritten policy of conservatism in adopting projects of B/C ratio less than about 1.20 to 1.00, and the growth in power demands ahead of schedule. With the exception of one or two small projects, the entire program of the Corps of Engineers now under construction shows up favorably, and most of the authorized reservoirs not yet started are equally sound, except for certain projects which already had been deferred for re-analysis.

It is the opinion of the writer that for the larger and more complex systems, Government planning and construction has resulted in bolder and more imaginative plans, with better consideration for the needs of the future and for non-power purposes, and a more complete utilization of stream flow for power output than would have resulted otherwise. On the other hand, for smaller streams, where power is the dominant purpose of water control and use, and where private thermal power is many times greater than hydroelectric potential, private development is probably more economical, and can certainly be accomplished more rapidly in any given case. The decision as to whether Federal, State or municipal agencies or private power companies should be chosen to build any given project of the planned system involves intangibles of a political nature. Questions as to the existing pattern of development in the area, relationship to other Federal projects, and extent to which other project purposes such as flood control are involved are obviously pertinent.

Once the basic decision is made that the Federal Government is the proper agency to develop a given power site, a natural advantage to longer range development exists than would be profitable for private investors, on account of lower interest rates. To avoid any possible misconceptions, the writer does not personally consider that this credit advantage should be grounds for

4. See pp. 53 to 56, "Proposed Practices for Economic Analysis of River Basin Projects" (often called the "Green Book"). Federal Inter-Agency Subcommittee on Costs and Benefits, May 1950.

the Federal Government undertaking other types of economic enterprises, which would otherwise be developed by private capital. The political decision in such cases should be paramount.

A good deal of study is currently being given by Government engineers to the relationship of hydro to thermal power, particularly as to peaking power. More study is needed along these lines. Moreover, special consideration should be given to the critical or design drouth period, in view especially of recent experience in the Southwest.

More attention should be given to economic principles in planning hydro-electric development; but such principles cannot be developed and applied other than in a context of sound engineering. Considerable of the argument regarding cost allocations, relationship of hydro to steam power, and tax and interest situations should be capable of more objective clarification. It would be helpful if economists as well as engineers would give more adequate attention to principles upon which a sound public power policy could be based.

Federal hydro-electric plants, when planned for use in conjunction with adjacent groups of thermal plants, should be designed and operated to produce an economical amount of dependable peaking capacity, under load conditions appropriate to the interconnected system as a whole. Valuation of power from such a project should be made in terms of dependable capacity and of total usable energy provided, rather than of the firm power which could be furnished to a group of customers by the hydro project operating alone.

The future of hydro electric developments throughout the United States, even ultimately in the Columbia Basin, will be as a supplementary source of electric power, particularly adopted for peaking purposes in thermal-hydro systems. As atomic thermal energy is added, the fossil fuels will ultimately become relatively less important and new developments of both hydro and conventional thermal plants will probably be curtailed. However, on account of their low operating costs, the hydro systems will remain useful elements, fulfilling their basic purposes for many years to come, unless large scale conversion of atomic energy directly to electricity becomes feasible.

TABLE I

FEDERAL HYDRO GENERATING CAPACITY AND TOTAL ELECTRIC UTILITY CAPACITY

	1944	1954
Federal hydro	4,482,350 kw	10,190,170 kw
Total utility	49,189,072 kw	102,520,056 kw
Percent Federal hydro	9.11%	9.94%

TABLE 2

MAJOR FEDERAL HYDROELECTRIC POWER PROGRAMS*

Agency	Total Installed thru 1954	Installations planned 1955-1957	Installations Planned After 1957	Total
Corps of Engineers - - -	2,816,800	2,436,600	2,883,000	8,136,400
Department of the Interior - - -	4,717,250	435,400	201,950	5,354,600
Tennessee Valley Authority - - -	2,668,000	74,500	-	2,742,500
	10,202,050	2,946,500	3,084,950	16,233,500

*Electrical World 24 January 1955

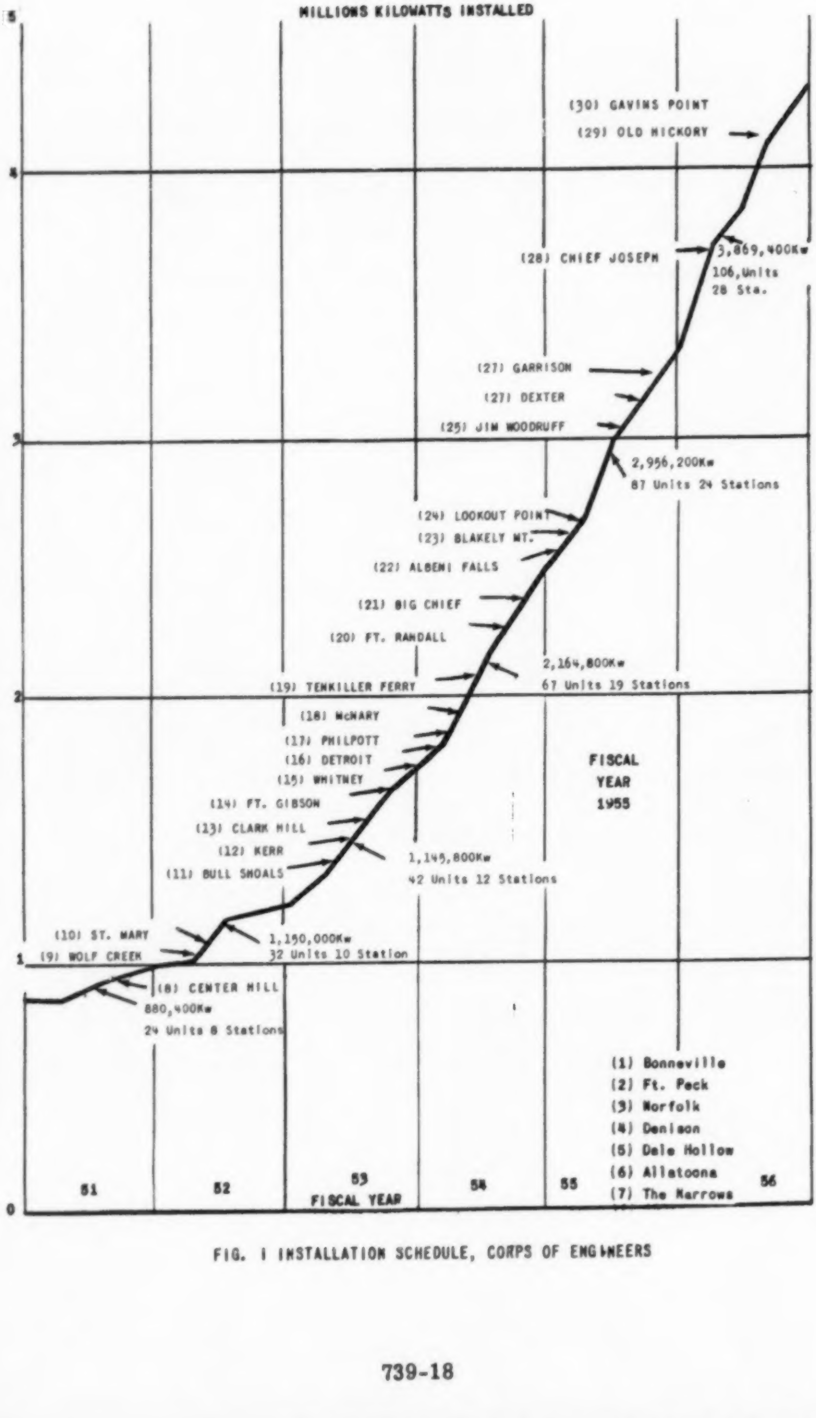


FIG. I INSTALLATION SCHEDULE, CORPS OF ENGINEERS

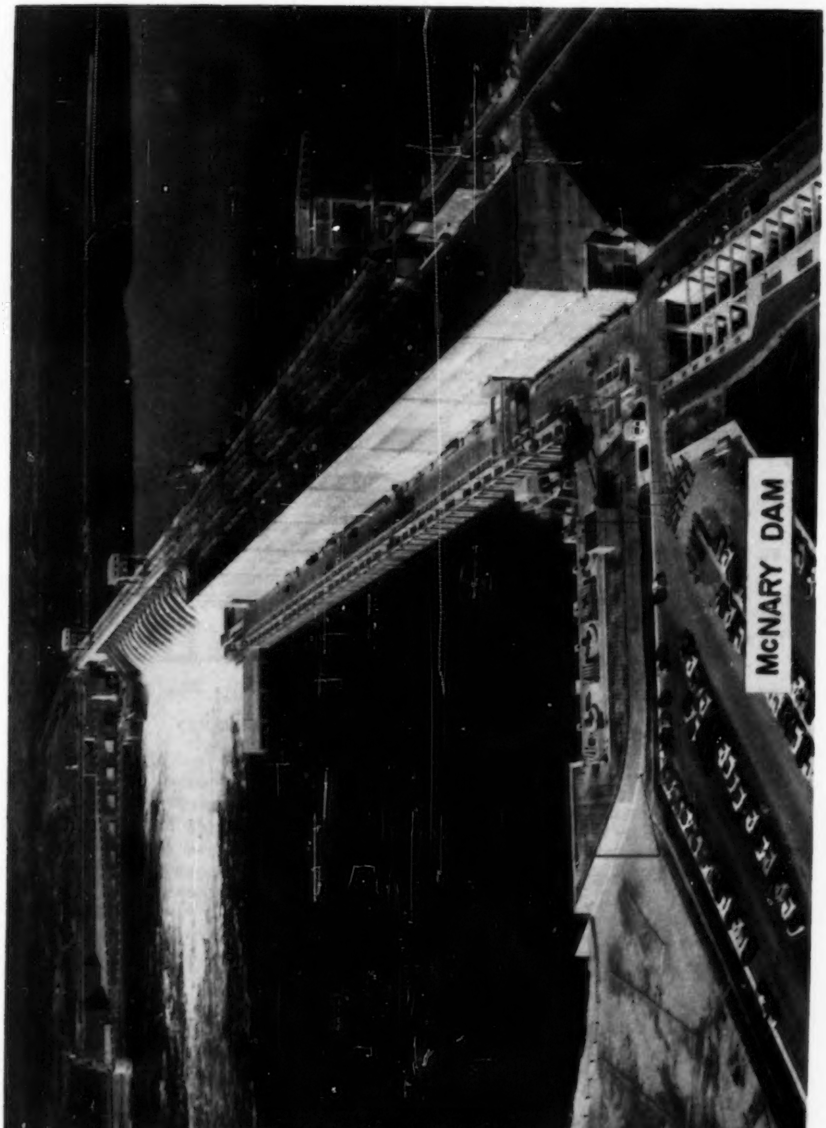
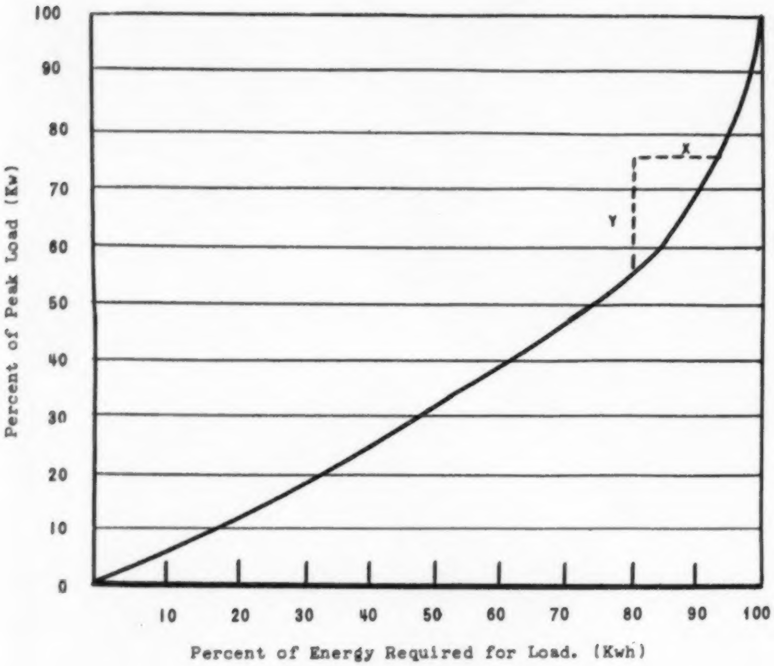


Figure 2.



NOTE: Intercepts "X" and "Y" for any section of curve indicate energy and peaking requirements required for that portion of the load in terms of percentages of the total requirements. For the portion of the load shown above, 20 percent of the peak load in kilowatts requires 15 percent of the total energy requirements.

FIG. 3 PERCENT - PERCENT CURVE OF POWER LOAD
(FOR ANY GIVEN PERIOD SUCH AS WEEK, MONTH OR YEAR)

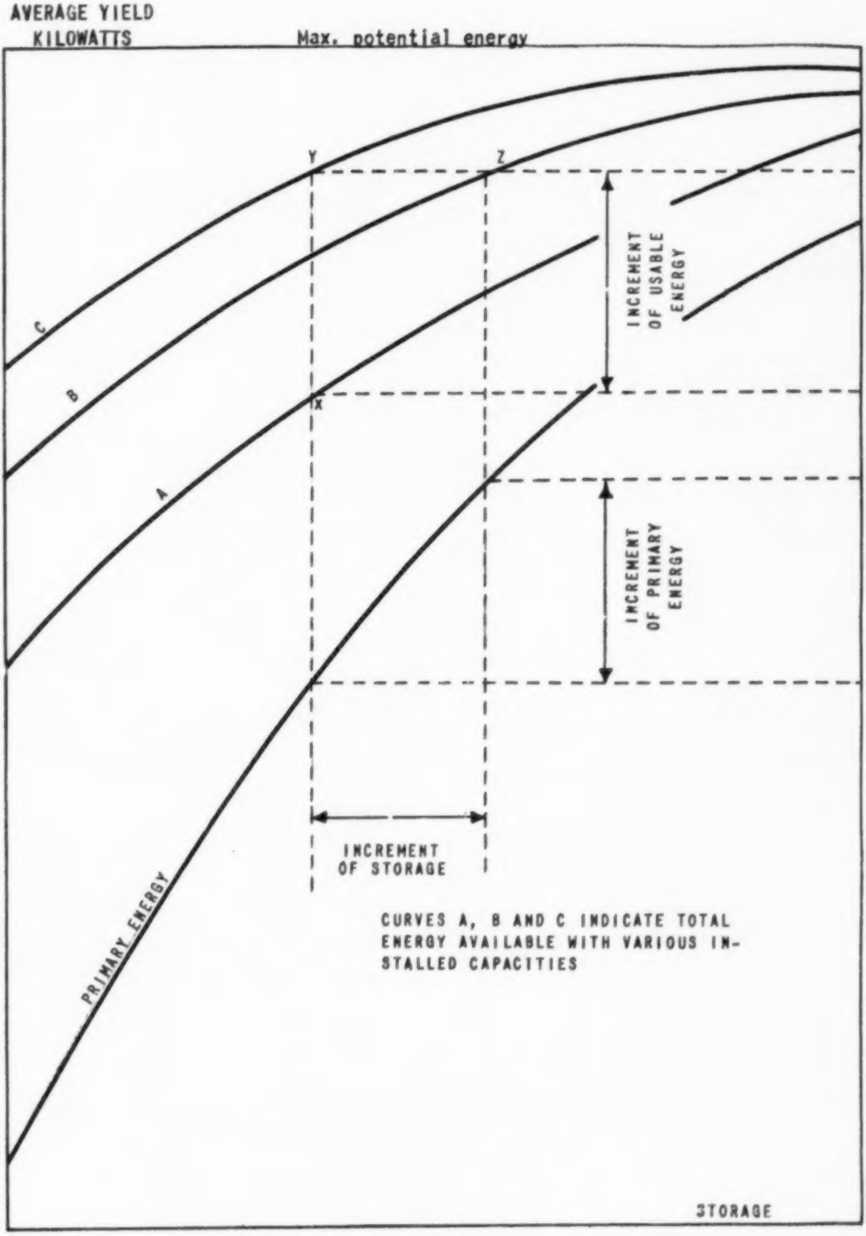


FIG. 4 STORAGE - INSTALLED CAPACITY YIELD CURVES